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A DETAILED STUDY OF THE OXIDATION  
DITCH AS A METHOD OF WASTEWATER  
TREATMENT AT CAMERON,  
WEST VIRGINIA

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West Virginia University  
Morgantown, West Virginia

November 1967

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(6/17)

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## Chapter I

### INTRODUCTION

West Virginia, like many other states, has a large number of small communities that do not have facilities for treating municipal wastes. As the need for high quality water increases it becomes even more urgent for these communities to correct this situation. Many of these small towns are under an economic strain to provide the services presently being offered without the additional burden of providing for the construction and operation of sewage treatment facilities. It is therefore essential that they be provided with a method of wastewater treatment which is adequate to provide a high degree of treatment at an economical cost.

Conventional wastewater treatment methods involving a number of separate units such as grit removal, sedimentation, sludge removal and digestion, and chlorination causes a high per capita construction cost for small communities. Oxidation ponds or sewage lagoons provide adequate treatment at much lower cost than conventional treatment but the large land areas needed for this method are many times not available.

It was for this reason that a study was instituted on the oxidation ditch method of waste treatment. The oxidation ditch functions much as an extended aeration plant with the treatment taking place in a circular or oval ditch. A mechanical wheel or rotor mixes air into the wastewater and also forces it to circulate about the ditch. The oxygen in the air coming into contact with the solids in the wastewater plus the velocity of movement keeping these solids in suspension provides for rapid decomposition of the organic matter.

This study was performed specifically in an attempt to evaluate construction and operating costs, chemical and bacteriological effectiveness, oxygen uptake and other items pertinent to the above factors.

## Chapter II

### THE OXIDATION DITCH AT CAMERON, WEST VIRGINIA

An oxidation ditch was constructed at Cameron, West Virginia during the latter part of 1964. Although the ditch was ready for operation by January 1965 the sewerage system in the town itself was not yet finished. Numerous construction problems hampered efforts to begin continuous operations until June 1965 and shortly after operation began the ditch lining material came loose and floated to the surface. Continuous operation did not actually begin until September 1965 and has continued since that time except for various mechanical malfunctions which have occurred from time to time.

Design criteria for the oxidation ditch were based on information published by J. K. Baars<sup>(9)</sup> and also on information from Lakeside Engineering Corporation of Chicago, Illinois<sup>(49)</sup>. The design engineers for the project were A. R. Todd and Associates, now known as Ceronne and Vaughn of Wheeling, West Virginia. Briefly the design was based on the following information:

Present Population - 1652

Design Population - 2400

Average Design Flow 240,000 gallons per day

5-Day 20°C BOD Loading 0.17 pounds per design capita  
plus 27 pounds for a small milk processing giving  
435 pounds per day.

Oxidation Ditch Volume - based on 74 cubic feet per  
pound of BOD equals 32,200 cubic feet.

Rotor length - based on entraining 2.32 pounds of  
oxygen for each pound of BOD, and on oxygen transfer

from the rotor of 2.83 pounds per hour per foot of rotor

$$\frac{435 \times 2.32}{24 \times 2.83} = 14.88 \text{ feet}$$

However the length of rotor needed to maintain a ditch velocity of one foot per second is 15.1 feet.

Therefore two rotors each 8 feet long were used giving a total length of 16 feet. The above rotor computations were based on a 27-1/2 inch diameter cage rotor, rotating at 75 revolutions per minute with an immersion depth of 6 inches.

Final settling tank designed for an overflow rate of 600 gallons per square foot per day and a 3 hour detention time.

Sludge Drying Bed designed for 1.0 square feet per population equivalent or  $2400 + \frac{27}{0.17} = 2400 + 160 = 2560$  PE or 2560 square feet.

The design also provides for a comminutor, chlorine contact chamber, a small laboratory, recirculating pumps, chlorinator and miscellaneous items plus a pump station and grit removal equipment some distance from the treatment plant.

The sequence of flow through the plant begins with the comminutor, and bar screen standby, which receives the sewage from the pumping station. After flow through the comminutor the sewage goes into the trapezoidal shaped ditch just upstream from one of the two cage rotors. It is then circulated around the ditch at approximately one foot per second velocity. The average detention time in the ditch is 24 hours, based on design flow. Half way around the ditch a submerged line picks up the ditch liquid and carries it over a weir and into a sump from which it is pumped to the clarifier. This weir can be used to

control depth of flow as it is made up of boards resting in slots. From the clarifier the effluent flows to the chlorine contact chamber and on out to the receiving stream. A bypass is provided around the chlorine contact chamber as well as from the ditch itself for emergency purposes. The sludge from the clarifier is either returned to the ditch or wasted to the sludge drying beds.

A plan view of the Cameron oxidation ditch is shown in Figure 1 while a cross sectional view is shown in Figure 2. Figures 3 through 13 showing various features of the Cameron plant follow and are identified beneath the photographs.

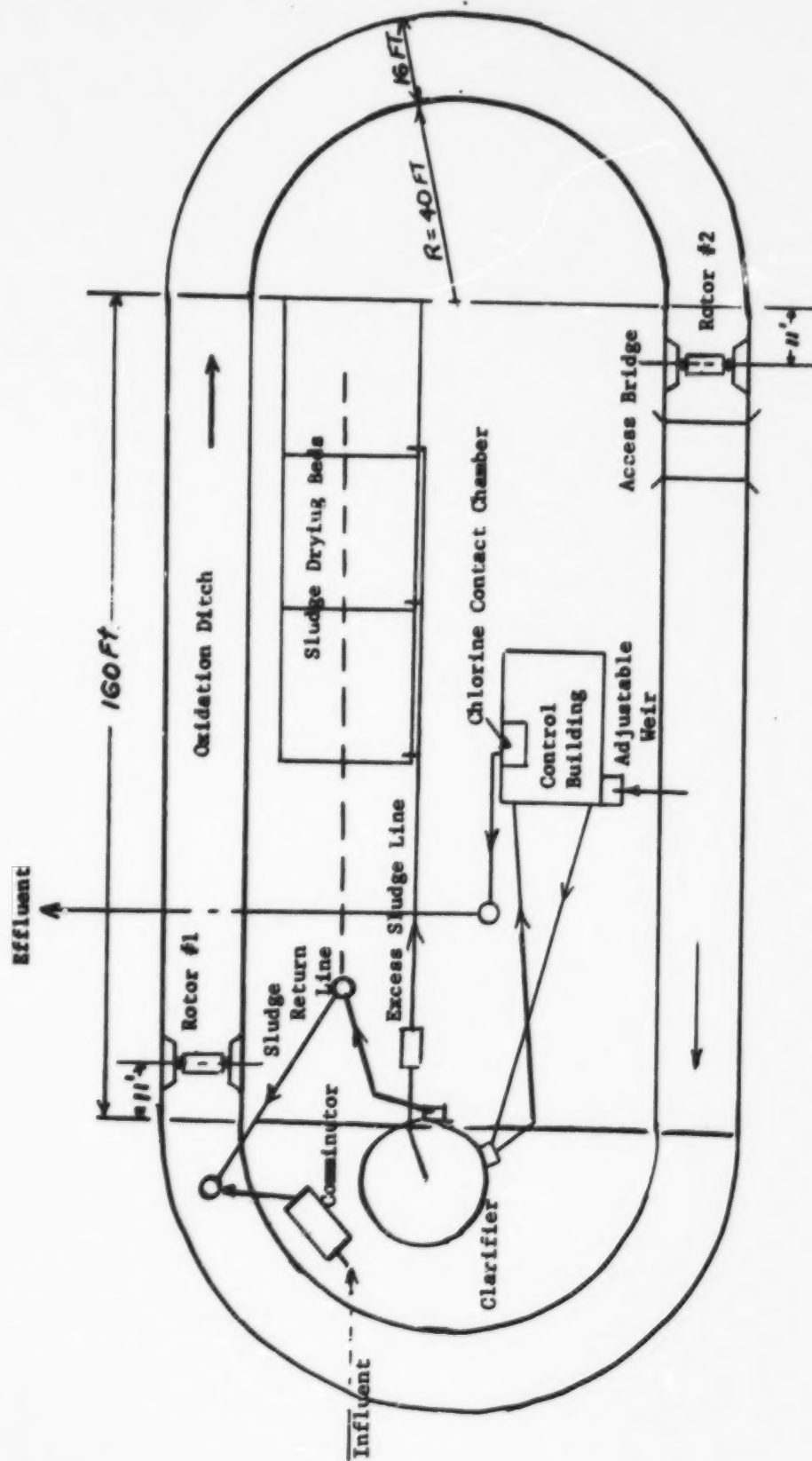


Figure 1 Cameron, W. Va. Oxidation Ditch - Plan View

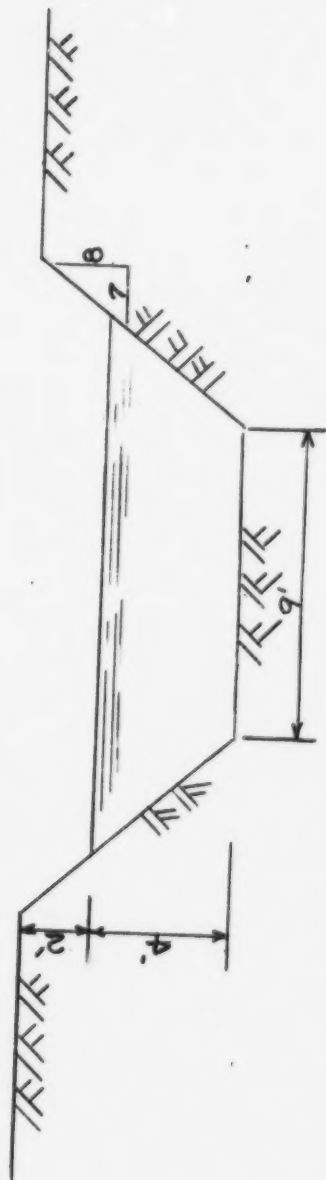


Figure 2 Cameron, W. Va. Oxidation Ditch - Cross Section



Figure 3 General View of Cameron, West Virginia  
Oxidation Ditch Sewage Treatment Plant

Figures standing at comminutor with Rotor #1 to the left and clarifier to the right. Sludge drying beds are seen at left center while building housing chlorine contact chamber, pumps, laboratory and miscellaneous items is at right center. Access bridge is to the right of the brick building and obscures Rotor #2.



Figure 4 Comminutor and Bar Screen



Figure 5 Rotor #1

Sewage Enters Ditch from Comminutor Just Upstream From This Point. Flow is From Left to Right.



Figure 6 Rotor #2

Flow is From Top Right to Bottom Left of Photograph.



Figure 7

Overflow Weir on Line From Ditch to Clarifier Pumps

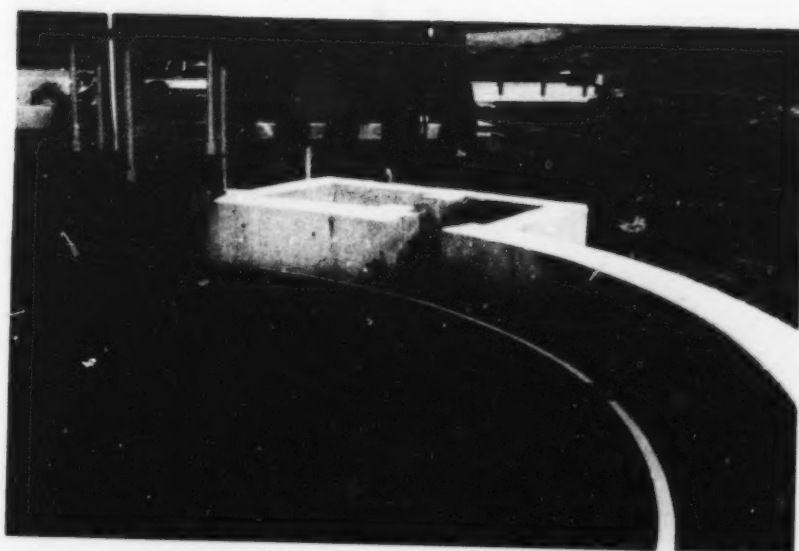


Figure 8 Clarifier



Figure 9 Sludge Drying Beds

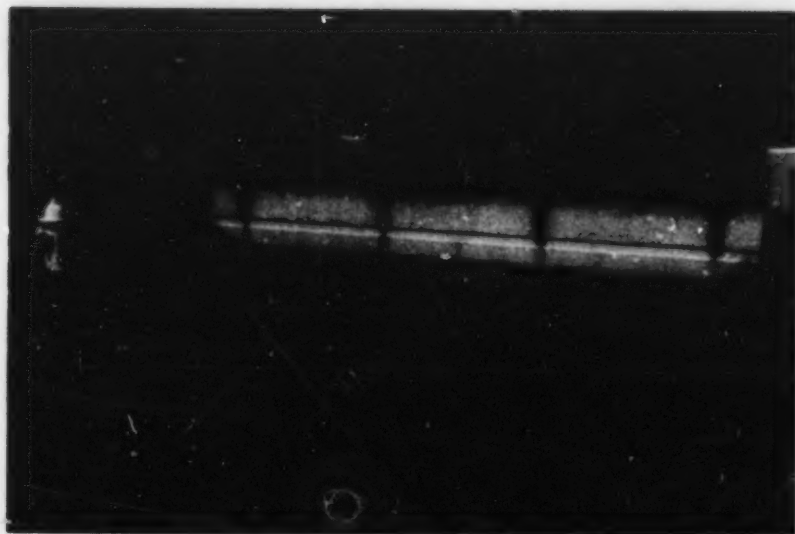


Figure 10 Access Bridge



Figure 11 Laboratory

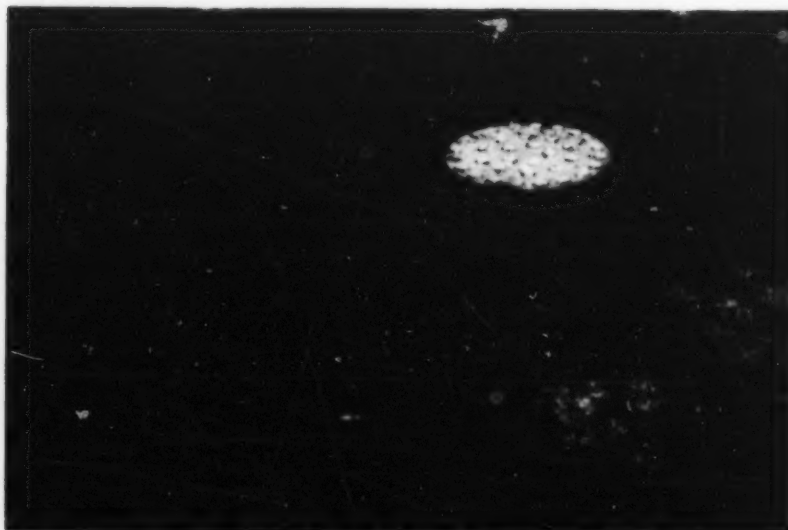


Figure 12 Manhole on Sludge Return Line

Difficulty was experienced here as line used to return sludge to ditch was not of sufficient capacity when sludge pump was operated unless pump discharge was throttled.



Figure 13 Current Meter Used for Velocity Measurements

### Chapter III

#### CHEMICAL AND BACTERIOLOGICAL STUDIES

Chemical tests were started on a regular basis in September 1965 and continued until August 1967.

Data were collected primarily on the sewage coming into the ditch, in the ditch itself and on the effluent, although some were collected on influent and effluent only as noted in table.

These data consisted of the following: suspended solids, volatile non-volatile and total, total solids, volatile and non-volatile and total, sludge volume index, chlorides, hardness, alkalinity, hydrogen ion concentration temperature, dissolved oxygen, BOD, COD, ABS, chlorides, hardness, specific conductance, ammonia nitrogen, nitrites, nitrates, phosphates, iron and copper.

Total bacteria count and coliform count were also made on the influent, the effluent, and the chlorinated effluent.

Average monthly sewage flows were also determined. Monthly averages are listed in the following tables for the year 1966.

1966

| Suspended Solids mg/l |          |  | Jan. | Feb. | Mar. | Apr. | May  | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
|-----------------------|----------|--|------|------|------|------|------|------|------|------|-------|------|------|------|
| Total                 | Influent |  | 37   | 44   | 33   | 79   | 59   | 162  | 210  | 156  | 343   | 288  | 66   | 40   |
|                       | Ditch    |  | 2461 | 2629 | 3559 | 2731 | 2624 | 2821 | 2739 | 2801 | 8580  | 9941 | 3359 | 3174 |
|                       | Effluent |  | 15   | 5    | 9    | 22   | 30   | 21   | 25   | 36   | 12    | 8    | 5    | 14   |
| Volatile              | Influent |  | 31   | 26   | 24   | 53   | 27   | 107  | 147  | 112  | 260   | 160  | 60   | 31   |
|                       | Ditch    |  | 1102 | 1169 | 1706 | 1688 | 1252 | 1340 | 1281 | 1101 | 2984  | 3389 | 1236 | 1277 |
|                       | Effluent |  | 12   | 3    | 5    | 8    | 22   | 14   | 19   | 27   | 8     | 5    | 4    | 4    |
| Non-volatile          | Influent |  | 6    | 18   | 9    | 26   | 32   | 55   | 63   | 44   | 83    | 128  | 6    | 11   |
|                       | Ditch    |  | 1359 | 1460 | 1853 | 1043 | 1372 | 1481 | 1458 | 1700 | 5596  | 6553 | 2123 | 1897 |
|                       | Effluent |  | 4    | 2    | 4    | 14   | 5    | 7    | 6    | 9    | 4     | 3    | 1    | 10   |

| Total Solids mg/l |          |  | Jan. | Feb. | Mar. | Apr. | May  | June | July | Aug. | Sept. | Oct.  | Nov. | Dec. |
|-------------------|----------|--|------|------|------|------|------|------|------|------|-------|-------|------|------|
| Total             | Influent |  | 273  | 275  | 236  | 392  | 309  | 700  | 942  | 809  | 1008  | 1010  | 453  | 336  |
|                   | Ditch    |  | 3013 | 2991 | 3814 | 2969 | 2891 | 3271 | 3338 | 3338 | 9074  | 10186 | 3613 | 3516 |
|                   | Effluent |  | 228  | 196  | 195  | 238  | 242  | 498  | 552  | 548  | 647   | 687   | 300  | 254  |
| Volatile          | Influent |  | 111  | 116  | 110  | 180  | 121  | 342  | 459  | 329  | 478   | 575   | 210  | 136  |
|                   | Ditch    |  | 1324 | 1355 | 1801 | 1450 | 1352 | 1556 | 1525 | 1310 | 3029  | 3396  | 1423 | 1391 |
|                   | Effluent |  | 83   | 76   | 81   | 97   | 97   | 263  | 243  | 221  | 267   | 321   | 103  | 82   |
| Non-volatile      | Influent |  | 162  | 159  | 126  | 212  | 188  | 358  | 483  | 480  | 530   | 435   | 243  | 200  |
|                   | Ditch    |  | 1689 | 1636 | 2013 | 1519 | 1539 | 1715 | 1813 | 2028 | 6045  | 6790  | 2190 | 2125 |
|                   | Effluent |  | 145  | 120  | 114  | 141  | 145  | 235  | 309  | 327  | 380   | 360   | 197  | 172  |

Table 1 Monthly Average of Physical and Chemical Data

1966

|                              | Jan. | Feb. | Mar. | Apr. | May  | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
|------------------------------|------|------|------|------|------|------|------|------|-------|------|------|------|
| <u>Sludge Volume Index</u>   | 57   | 80   | 80   | 28   | 53   | 31   | 18   | 24   | 26    | 44   | 78   | 74   |
| <u>Chlorides mg/l</u>        |      |      |      |      |      |      |      |      |       |      |      |      |
| <u>Influent</u>              | 15   | 18   | 12   | 14   | 15   | 42   | 76   | 66   | 51    | 40   | 73   | 20   |
| <u>Ditch</u>                 | 11   | 20   | 13   | 12   | 12   | 38   | 53   | 53   | 50    | 42   | 55   | 21   |
| <u>Effluent</u>              | 11   | 18   | 12   | 12   | 12   | 36   | 51   | 52   | 50    | 44   | 52   | 20   |
| <u>Hardness mg/l</u>         |      |      |      |      |      |      |      |      |       |      |      |      |
| <u>Influent</u>              | 139  | 176  | 154  | 102  | 82   | 155  | 162  | 198  | 184   | 160  | 121  | 90   |
| <u>Ditch</u>                 | 150  | 180  | 114  | 111  | 80   | 140  | 160  | 180  | 186   | 140  | 119  | 91   |
| <u>Effluent</u>              | 127  | 216  | 98   | 100  | 80   | 132  | 165  | 176  | 188   | 127  | 107  | 90   |
| <u>pH</u>                    |      |      |      |      |      |      |      |      |       |      |      |      |
| <u>Influent</u>              | 7.3  | 7.2  | 7.2  | 7.4  | 7.3  | 7.1  | 7.0  | 7.1  | 7.3   | 7.3  | 7.5  | 7.2  |
| <u>Ditch</u>                 | 7.1  | 7.2  | 7.2  | 7.3  | 7.4  | 7.3  | 7.4  | 7.0  | 7.2   | 7.2  | 7.4  | 7.5  |
| <u>Effluent</u>              | 7.4  | 7.2  | 7.3  | 7.3  | 7.3  | 7.3  | 7.4  | 7.3  | 7.0   | 7.1  | 7.3  | 7.6  |
| <u>Dissolved Oxygen mg/l</u> |      |      |      |      |      |      |      |      |       |      |      |      |
| <u>Influent</u>              | 6.0  | 7.9  | 5.5  | 5.4  | 5.5  | 5.0  | 4.8  | 4.6  | 4.0   | 3.5  | 4.5  | 4.0  |
| <u>Ditch</u>                 | 9.0  | 7.2  | 5.2  | 5.4  | 5.9  | 5.9  | 5.8  | 6.2  | 6.0   | 6.2  | 6.6  | 5.5  |
| <u>Effluent</u>              | 9.5  | 7.8  | 5.3  | 5.5  | 6.0  | 6.1  | 6.0  | 6.0  | 7.9   | 7.3  | 7.1  | 5.7  |
| <u>Alkalinity mg/l</u>       |      |      |      |      |      |      |      |      |       |      |      |      |
| <u>Influent</u>              | 83   | 70   | 88   | 107  | 108  | 202  | 214  | 284  | 146   | 141  | 140  | 118  |
| <u>Ditch</u>                 | 76   | 76   | 88   | 94   | 122  | 167  | 199  | 172  | 135   | 152  | 199  | 111  |
| <u>Effluent</u>              | 70   | 58   | 75   | 89   | 109  | 161  | 178  | 140  | 122   | 116  | 101  | 93   |
| <u>ABS mg/l</u>              |      |      |      |      |      |      |      |      |       |      |      |      |
| <u>Influent</u>              | 2.42 | 0.72 | 0.75 | 1.18 | 0.30 | 0.91 | 0.66 | 0.78 | 1.16  | 1.10 | 0.82 | 0.70 |
| <u>Ditch</u>                 | 1.02 | 0.17 | 0.32 | 0.60 | 0.30 | 0.68 | 0.18 | 0.24 | 0.42  | 0.36 | 0.28 | 0.42 |
| <u>Effluent</u>              | 0.24 | 0.18 | 0.16 | 0.20 | 0.30 | 0.22 | 0.16 | 0.14 | 0.22  | 0.18 | 0.14 | 0.20 |
| <u>BOD mg/l</u>              |      |      |      |      |      |      |      |      |       |      |      |      |
| <u>Influent</u>              | 109  | 80   | 120  | 150  | 175  | 181  | 190  | 222  | 228   | 414  | 368  | 200  |
| <u>Effluent</u>              | 15   | 5    | 7    | 9    | 5    | 7    | 9    | 23   | 11    | 11   | 10   | 8    |

Table 1 (continued)

1966

|                                | Jan. | Feb. | Mar. | Apr. | May  | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
|--------------------------------|------|------|------|------|------|------|------|------|-------|------|------|------|
| <u>Per Cent Removal of BOD</u> | 86.2 | 93.8 | 94.0 | 94.0 | 97.2 | 96.2 | 95.3 | 89.6 | 95.3  | 97.5 | 97.3 | 96.0 |
| <u>COD mg/l</u>                |      |      |      |      |      |      |      |      |       |      |      |      |
| <u>Influent</u>                | 610  | 542  | 498  | 510  | 580  | 565  | 565  | 578  | 544   | 537  |      |      |
| <u>Effluent</u>                | 57   | 63   | 80   | 85   | 80   | 93   | 85   | 55   | 53    | 31   |      |      |
| <u>Specific Conductance</u>    |      |      |      |      |      |      |      |      |       |      |      |      |
| <u>Influent</u>                | 10.0 | 10.6 | 8.3  | 11.9 | 10.7 | 19.0 | 23.7 | 22.8 | 33.6  | 37.2 | 16.5 | 12.4 |
| <u>Effluent</u>                | 9.6  | 10.5 | 9.3  | 10.3 | 10.1 | 18.2 | 18.5 | 19.9 | 25.9  | 28.7 | 14.4 | 11.6 |
| <u>Ammonia Nitrogen</u>        |      |      |      |      |      |      |      |      |       |      |      |      |
| <u>Influent</u>                | 3.6  | 4.6  | 3.8  | 4.2  | 6.8  | 6.2  | 2.3  | 27.0 | 39.0  | 41.0 | 10.2 | 6.4  |
| <u>Effluent</u>                | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 13.0 | 0.8   | 1.0  | 0    | 0    |
| <u>Nitrite Nitrogen</u>        |      |      |      |      |      |      |      |      |       |      |      |      |
| <u>Influent</u>                | 0.04 | 0.03 | 0.05 | 0.04 | 0.02 | 0.02 | 0.02 | 0.04 | 0.05  | 0.04 | 0.03 | 0.02 |
| <u>Effluent</u>                | 0.10 | 0.10 | 0.06 | 0.09 | 0.10 | 0.02 | 0.06 | 0.10 | 0.11  | 0.08 | 0.04 | 0.02 |
| <u>Nitrate Nitrogen</u>        |      |      |      |      |      |      |      |      |       |      |      |      |
| <u>Influent</u>                | 13.0 | 4.5  | 3.7  | 0.8  | 33.0 | 6.0  | 12.2 | 14.4 | 0.9   | 1.0  | 12.4 | 16.0 |
| <u>Effluent</u>                | 39.0 | 10.0 | 20.0 | 7.5  | 47.0 | 16.0 | 20.6 | 31.1 | 6.7   | 10.8 | 25.5 | 30.2 |
| <u>Phosphate mg/l</u>          |      |      |      |      |      |      |      |      |       |      |      |      |
| <u>Influent</u>                | 10   | 36   | 13   | 5    | 34   | 19   | 23   | 6    | 4     | 20   | 40   | 15   |
| <u>Effluent</u>                | 15   | 11   | 4    | 5    | 4    | 8    | 9    | 5    | 3     | 12   | 20   | 4    |
| <u>Iron mg/l</u>               |      |      |      |      |      |      |      |      |       |      |      |      |
| <u>Influent</u>                | 0.16 | 0.24 | 0.16 | 0.31 | 0.29 | 0.30 | 0.18 | 0.28 | 0.16  | 0.21 | 0.25 | 0.20 |
| <u>Effluent</u>                | 0.16 | 0.20 | 0.20 | 0.25 | 0.22 | 0.14 | 0.15 | 0.18 | 0.10  | 0.15 | 0.15 | 0.20 |
| <u>Copper mg/l</u>             |      |      |      |      |      |      |      |      |       |      |      |      |
| <u>Influent</u>                | 0.20 | 0.13 | 0.15 | 0.11 | 0.18 | 0.11 | 0.16 | 0.18 | 0.21  | 0.09 | 0.12 | 0.14 |
| <u>Effluent</u>                | 0.27 | 0.15 | 0.15 | 0.17 | 0.12 | 0.16 | 0.10 | 0.4  | 0.15  | 0.12 | 0.10 | 0.15 |
| <u>Temp. °C</u>                |      |      |      |      |      |      |      |      |       |      |      |      |
| <u>Influent</u>                | 4.0  | 4.2  | 5.1  | 5.9  | 10.5 | 15.2 | 22.0 | 22.2 | 18.5  | 13.6 | 7.7  | 5.0  |

Table 1 (continued)

1966

|                                         | Jan. | Feb. | Mar. | Apr. | May  | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
|-----------------------------------------|------|------|------|------|------|------|------|------|-------|------|------|------|
| <u>Total Bacteria per ml</u>            |      |      |      |      |      |      |      |      |       |      |      |      |
| <u>All values reported in thousands</u> |      |      |      |      |      |      |      |      |       |      |      |      |
| <u>Influent</u>                         | 250  | 270  | 100  | 381  | 180  | 100  | 235  | 220  | 61    | 303  | 250  | 200  |
| <u>Effluent</u>                         | 3.5  | 3.4  | 0.6  | 2.1  | 2.2  | 4.6  | 9.7  | 1.7  | 5.6   | 19   | 9.0  | 8.2  |
| <u>Chlorinated Effluent</u>             | 0.5  | 0.3  | 0.2  | 0.4  | 0.2  | 0.2  | 0.4  | 0.5  | 0.1   | 0.2  | 0.3  | 0.2  |
| <u>Coliform per ml</u>                  | 109  | 2250 | 2500 | 3250 | 1125 | 875  | 1500 | 1460 | 362   | 530  | 896  | 1012 |
| <u>Effluent</u>                         | 26   | 50   | 42   | 6    | 18   | 50   | 112  | 5    | 46    | 34   | 22   | 20   |
| <u>Chlorinated Effluent</u>             | 5    | 0    | 0    | 0    | 0    | 5    | 0    | 0    | 0     | 0    | 0    | 0    |

Table 2 Bacteriological Data - 1966

| <u>Month and Year</u> | <u>Average Daily Flow in Gallons</u> |
|-----------------------|--------------------------------------|
| January 1966          | 438,000                              |
| February              | 314,000                              |
| March                 | 322,000                              |
| April                 | 409,133                              |
| May                   | 390,000                              |
| June                  | 130,533                              |
| July                  | 89,935                               |
| August                | 89,354                               |
| September             | 69,400                               |
| October               | 77,290                               |
| November              | 177,034                              |
| December              | 336,161                              |

Table 3 Sewage Flow

Conclusions:

1. No difficulty was experienced in keeping the solids in the ditch in suspension. Total suspended solids in the ditch generally ran somewhat lower than desirable.
2. At no time to date has it been necessary to pump excess sludge to the drying beds.
3. Overall reduction of total solids between the influent and effluent has been slight.
4. Dissolved oxygen has been consistently high in the ditch and effluent.
5. Nitrates have generally increased from influent to effluent but phosphates have been reduced.
6. Chlorination of the effluent is necessary to insure destruction of the coliform organisms.
7. BoD removal efficiency has been extremely good showing percentages above 90 per cent for all but two months. BOD remaining in effluent has been quite constant and appears to be more or less independent of the BOD in the influent.

## Chapter IV

### VELOCITY STUDIES

Since the oxidation ditch is essentially an extended aeration treatment it is essential that the organic matter be kept in a state of suspension. For this reason studies were made of velocity distribution in the ditch and calculations were also performed in order to estimate the required critical velocity for keeping the organic solids in suspension.

Using a specific gravity of 1.008 for the organic particles a critical velocity of 0.136 feet per second was determined. Realizing that many particles will vary in size and specific gravity it is generally assumed that ditch velocity should be near 1.0 feet per second.

On this basis velocity distribution was studied at various cross sections around the ditch. Seven locations across the ditch were laid off at 2, 4, 6, 8, 10, 12, 14 feet, measured from the inside edge of the ditch, whose water surface was 16 feet in width. At each of these locations velocities were measured vertically at the surface and at 0.2, 0.4, 0.6, and 0.8 depth, using a current meter.

All told 22 cross-sections were laid off around the ditch but since the ditch is symmetrical with respect to the two rotors most measurements were made in only 11 of the cross-sections. Thirty-five vertical velocity measurements were made at each section.

Most of the measurements were made with the rotor operating at its design immersion of 6 inches but measurements were also made with rotor immersions of 4 inches and 8-1/2 inches and with one rotor only operating.

A typical cross-section of velocities is shown in Figure 14. This section is 117 feet downstream from rotor #2 (See Figure 1).

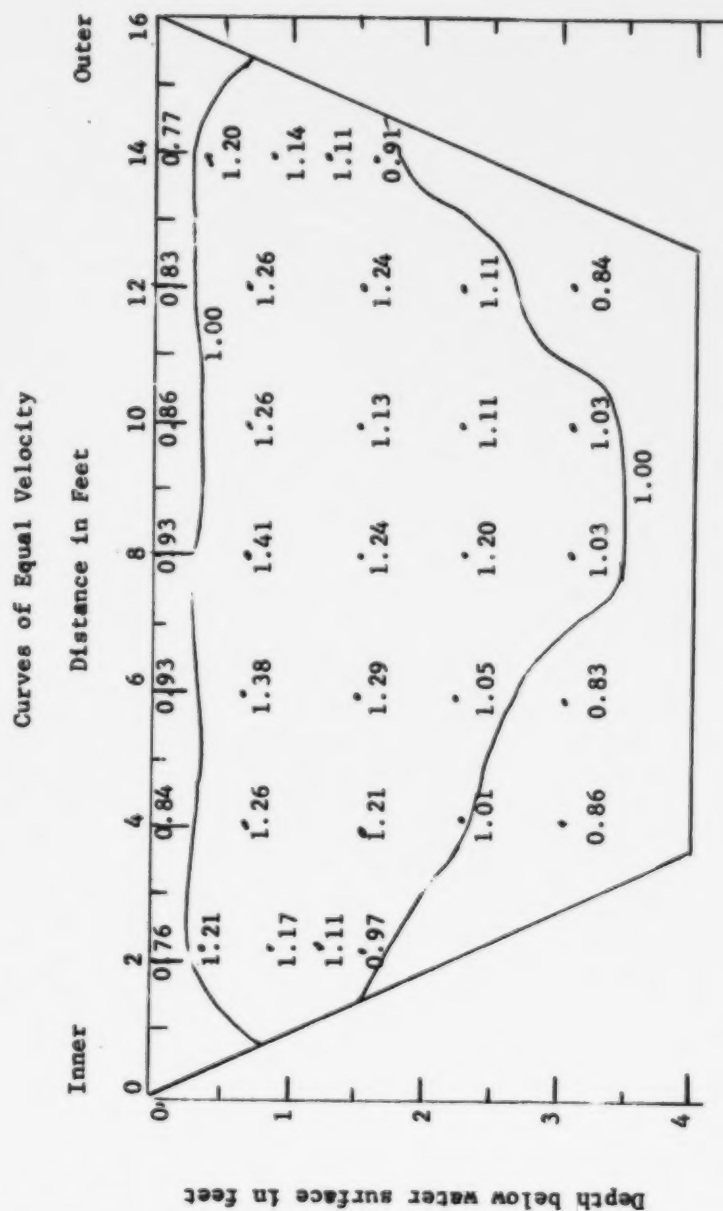


Figure 14 Velocity Distribution In A Typical Cross Section  
(Depth of Immersion = 6", Both Rotors Operating)

Conclusions:

1. Owing to the presence of a free surface and to friction along the channel wall, the velocities in a channel are not uniformly distributed in the channel section horizontally or vertically. The velocity distribution in a channel section depends upon several factors, such as the shape of the section, the roughness of the channel, the mean velocity, Reynolds number, intensity of the turbulence, and the presence of curves in the channel. In a broad, rapid and shallow stream or in a very smooth channel, the maximum velocity is often to be found at the free surface. The roughness of the channel will cause the curvature of the vertical velocity distribution curve to increase. In a curve the velocity increases at the inner bank, due to the centrifugal forces on the flow and transverse currents which are generated within the curving flow.
2. From the experimental results ( $D = 6''$ , both rotors operating), the velocity distributions are largely between 1.00 ft/sec. and 1.50 ft/sec. except at the water surface and below the 0.8 depth. The average mean velocity greater than 1 ft/sec. is sufficient to transport the solid matter while the mixed liquor travels around the ditch.

A study of vertical velocity curves concluded that in the straight portion of the ditch the maximum velocity occurred somewhere between the water surface and one-third of the depth. But in the curved portion of the ditch the maximum velocity occurred somewhere around the middle of the depth.
3. To compare the measured experimental mean velocity of greater than 1 ft/sec. with the calculated critical velocity of 0.136 ft/sec. it seems unlikely that any solid matter would deposit on the bottom of the

oxidation ditch. However some bottom deposits were found.

The mixed liquor coming to the oxidation ditch system brings with it two types of solids, organic and inorganic. Inorganic solids are sand, silt, cinders and other inert items that are not affected by bacteria or other organisms. Organic solids are human wastes, food wastes and other items that decay and can be broken down to simple compounds by bacteria and other organisms. An oxidation ditch sewage treatment plant is not designed to treat the inorganic solids, and these will either pass through the plant and be discharged with the effluent or will settle on the ditch bottom and build up as time passes on.

When there are some deposits existing on the ditch bottom, the mixed liquor velocity equals zero at that area and the adjacent flow velocity will also be reduced. In order to avoid such phenomena and keep solids in suspension, it is recommended that a periodical (about 6 months) cleanup of the bottom of the oxidation ditch be made.

4. Measurement of velocity when made at comparable sections on opposite sides of the ditch showed no appreciable variation.
5. The rotor immersion depth is the most important factor affecting the velocity distribution in the oxidation ditch. The correlation between them was made by the measurements of velocity at one section. The results show that the velocity distribution is more uniform when the rotor immersion depth equals 6 inches. If the rotor immersion depth increases, the flow velocity increases and the reverse is also true. Since an increase or decrease in the rotor immersion depth will cause extremes in velocity flow, it is recommended that the rotor be operated at a 6 inches depth.

Observations made with only one rotor operating showed extreme variations in velocity especially as the section on which observations were being made became farther removed from the operating rotor. More vertical variation was evidenced at any particular section and the overall velocity in the ditch became less, making the possibility of solids deposition more likely.

6. The path of the thread of maximum velocity moves from the outside wall right after the rotor toward the center line in the straight portion of the ditch. In the curved portion of the ditch, the path deviates from its normal course at a section upstream from the bend until it almost touches the inside wall. Beyond the curved portion the path gradually moves outward again until right before the other rotor. This flow pattern coincides with the experimental results obtained by Shukry<sup>(82)</sup> as shown in Chow's book,<sup>(18)</sup> "Open Channel Hydraulics."

## Chapter V

## CAPITAL COST STUDIES

In order to determine whether the oxidation ditch was an economical method of waste treatment a capital cost study was made. It should be remembered that the oxidation ditch is essentially providing secondary treatment since efficiency of BOD removal is generally above 90 per cent.

This study was accomplished by sending a questionnaire to all known consulting engineers who had designed oxidation ditches. These cost data were then analyzed by obtaining the cost per population equivalent and running regression analyses to determine the best linear fit.

These data were further adjusted for plant location and to April 1966.

Costs were also investigated considering plants without comminutors, without drying beds, and without sedimentation tanks.

Conclusions:

1. A regression analysis indicated that the 1,000 population equivalent level capital costs ranged between \$29 and \$68, with an average of \$45 per capita, based on the national cost index for April, 1966. These figures increase with a decrease in population and vice versa.

A study of activated sludge plants, adjusted to the same date give a range of costs of from \$50 to \$114 per capita at the 1,000 population equivalent level with an average of \$76 per capita.

2. The addition of a bar screen and the elimination of a comminutor from the basic design of an oxidation ditch would save the community from \$700 to \$1700 in initial costs.

3. By using the ditch as the sedimentation tank initial savings of \$7500 to \$20,000 could be obtained. This would no doubt necessitate a change in design so that continuous operation could be obtained.
4. Construction costs per gallon of flow for oxidation ditches ranged from \$0.35 for a population equivalent of 5000 to \$0.83 for a population equivalent of 250. This compares with \$0.53 to \$2.37 per gallon of flow for the same population equivalents for package treatment plants.

## Chapter VI

### OPERATING COST STUDIES

The operating cost of the oxidation ditch wastewater treatment plant at Cameron, West Virginia is defined as the sum of salary, power, chemical and miscellaneous costs. The miscellaneous cost is made up of such things as repairs, soap and towels, gasoline for the power mower, etc.

Power measurements were made on sewage pumps #1, #2, #3 and #4, comminutor, Rotor #1, Rotor #2, chlorine water pump and sludge pump. Additional power measurements were also made on a small submersible pump, a general purpose pump, heaters in the laboratory, wash room, chlorine room, blower room and hall and on ventilating fans in the roof, the chlorine room and the air intake vent.

#### Conclusions:

1. A unit annual operating cost of \$104.50 per million gallons of raw sewage treated prevails. This may also be expressed as \$5.48 per capita per year based on actual population or \$3.35 per capita per year based on design population.
2. Compared with the operating costs of two extended aeration plants in Ohio the operating costs of the oxidation ditch were 46.6 per cent less.
3. Compared with the operating costs of two contact stabilization plants in Ohio the operating cost of the oxidation ditch was 71.8 per cent less.

## Chapter VII

### STREAM STUDIES

Prior to construction of the oxidation ditch at Cameron, West Virginia the chemical and biological properties of Grave Creek were determined for comparative purposes.

Prior to the construction of the treatment plant and sewer system bringing the sewage to the plant there were 293 outlets discharging domestic wastes of the town into Grave Creek.

Four sampling points were established along the course of the stream. One as the stream entered the city limits, one approximately mid-way through the town, one near the proposed location for the treatment plant and one about 2 miles downstream from the treatment plant location.

Chemical tests conducted were: (1) Dissolved oxygen, (2) Alkalinity, (3) 5-Day Biochemical oxygen demand, and (4) pH.

Biological tests conducted were: (1) Plankton counts, (2) Bottom-Fauna Analysis (types and number), and (3) Bacteriological Analysis.

The results of these data are shown in Table 4.

| Station                                            | Dissolved<br>Oxygen<br>(mg/l) | pH  | 5 Day<br>BOD<br>(mg/l) | Total<br>Alkalinity<br>(mg/l as<br>CaCO <sub>3</sub> ) | Standard Plate Count<br>(48 hrs. 20°C)<br>(Bact/ml) | Plankton<br>Count<br>(total/liter) |
|----------------------------------------------------|-------------------------------|-----|------------------------|--------------------------------------------------------|-----------------------------------------------------|------------------------------------|
| Upper Edge of Town                                 | 10.59                         | 7.9 | 15.48                  | 197                                                    | -----                                               | 1425                               |
| Mid Town                                           | 2.34                          | 8.0 | 30.65                  | 221                                                    | -----                                               | 985                                |
| Treatment Plant Size                               | 1.57                          | 7.4 | 137.80                 | 249                                                    | 190,000                                             | 3400                               |
| 2 Miles downstream<br>from treatment plant<br>site | 8.78                          | 8.3 | 2.90                   | 221                                                    | 48,000                                              | 4475                               |

Table 4 Typical Data for September, 1964

Conclusions: Before Treatment Plant Construction

1. Grave Creek was polluted by domestic wastes from the town of Cameron, West Virginia.
2. The degree of pollution varied from mild to gross (by the standard definition of these terms), depending on the amount of water available in the creek.
3. During periods of normal stream flow chemical and biological characteristics indicate the following degree of pollution at the various stations.

| <u>Station</u>                       | <u>Condition</u>     |
|--------------------------------------|----------------------|
| Upper Edge of Town                   | Recent Pollution     |
| Mid Town                             | Active Decomposition |
| Treatment Plant Site                 | Strong Pollution     |
| Downstream from Treatment Plant Site | Mild Pollution       |

4. According to the stream classification adopted by the Potomac River Basin the waters of Grave Creek should not be used for any purpose without substantial treatment.

Similar studies were conducted on the stream during the period of study of the oxidation ditch. No apparent change was noted at the first station at the under edge of the town but at the remaining stations the dissolved oxygen was significantly increased seldom dropping below 5 mg/l while the biochemical oxygen demand was virtually eliminated. All of this change cannot be attributed to the treatment plant as the construction of the interceptor sewer was of course responsible for the reduction in BOD at the mid-town and treatment plant station.

Standard coliform count downstream from the plant has been drastically reduced but not eliminated.

Since nitrate in the plant effluent is in the range of 20 mg/l and phosphate in the range of 10 mg/l algae growth downstream is sometimes significant.

Typical algae identified (Genera): Anacystis, Ankistrodesmus, Bumilleria, Closterium, Glycylotella, Euglena, Fragilaria, Gomphonema, Hyalotheca, Micraspora, Navicula, Oscillatoria, Synedra, Spirogyra, Tribonema, Uluthrix, Zygnema.

Conclusions: After Treatment Plant Construction

1. Reduction in BOD and increase in DO in the stream has been significant.
2. Additional nutrients from treatment plant effluent has resulted in higher quantities of algae.

## Chapter VIII

### OXYGEN UPTAKE STUDIES

The purpose of this study was that of oxygen transfer in the oxidation ditch at Cameron, West Virginia.

Measurements were made at different depths in the ditch, at different cross sections for various rotor immersions.

Consideration was given to the fact that some aeration would be caused by surface contact as well as that introduced by the rotors themselves.

#### Conclusions:

1. As rotor immersion depth increases from 5 to 10 inches the transfer of oxygen across each rotor increases from 0.39 to 0.59 mg/l. After increasing across the rotor the dissolved oxygen concentration gradually decreases between rotors at a uniform rate of about 0.1 mg/l per 100 feet. No significant fluctuation in oxygen concentration as a function of depth was observed.
2. A large diurnal variation in oxygen level was observed. Oxygen concentration reaches a maximum around 6:00 A.M. and then steadily decreases throughout the day to a minimum around mid or late afternoon. Thus oxygen is being consumed faster than the rotors can supply it for almost a 10 hour period. The total variation on the days which were studied was as much as 4.4 mg/l. The rise and fall in oxygen level was shown to be due to changes in the microbial respiration rate. The data show that the microbial oxygen uptake rate varied from a minimum of 1.9 mg/l/hour in the early morning to a maximum of 10.3 mg/l/hour in mid-afternoon. Thus, the respective

maximum and minimum values for ditch oxygen concentration and oxygen uptake are complementary.

3. Rotor power consumption increased linearly from 0.33 KW to 1.29 KW as the rotor immersion depth increased from 0 to 11 inches. The most efficient rotor depth was found to be 7 inches at which the oxygen transfer rate was 7.03 lbs- $O_2$ /KWH.
4. For a typical day, the amount of oxygen transferred into the ditch due to the rotors and surface aeration was estimated to be 294 lbs- $O_2$ /day and 18 lbs- $O_2$ /day respectively. Microbial oxygen uptake was 297 lbs- $O_2$ /day.
5. The oxygenation capacity of the system under standard conditions of 20°C and 760mm mercury pressure was estimated to be 673 lbs- $O_2$ /day or 1.75 lbs- $O_2$ -hr/ft. of rotor.

CHAPTER IX  
MICROBIOLOGICAL STUDIES

The reduction of coliform organisms in sewage is one of the objectives of various waste treatment processes and the environment established in an oxidation ditch is such that a marked reduction in the coliform population is achieved.

Weekly samples for bacteriological analysis were collected from the oxidation ditch at Cameron from January to September, 1967. These consisted of a 3 hour composite sample.

Quantitative estimations of micro organisms were made by standard agar plate count procedures.

Coliform bacteria determinations were made using the membrane filter technique.

The results of these analyses are shown in Table 5.

| Date         | Flow<br>Gal./Day | Sewage<br>Temperature | Total Bacteria |          | Coliforms |          |
|--------------|------------------|-----------------------|----------------|----------|-----------|----------|
|              |                  |                       | Influent       | Effluent | Influent  | Effluent |
| January 1967 | 232,600          | 4°C                   | 250,000        | 3,500    | 109       | 26       |
| February     | 230,000          | 4                     | 270,000        | 3,365    | 2,250     | 50       |
| February     | 233,000          | 3                     | 381,500        | 2,115    | 3,250     | 13       |
| March        | 313,000          | 5                     | 180,000        | 2,150    | 1,125     | 18       |
| March        | 85,000           | 2                     | 100,000        | 4,600    | 875       | 50       |
| April        | 227,000          | 3                     | 235,000        | 9,700    | 1,500     | 125      |
| April        | 289,000          | 5                     | 220,000        | 1,670    | 1,460     | 9        |
| April        | 361,000          | 6                     | 61,000         | 5,600    | 362       | 46       |
| May          | 330,000          | 15                    | 303,000        | 19,000   | 530       | 34       |
| August       | 148,000          | 20                    | 200,000        | 2,900    | 1,450     | 90       |
| August       | 113,000          | 19                    | 326,500        | 14,150   | 3,760     | 30       |
| September    | 145,000          | 17                    | 215,000        | 6,800    | 2,900     | 81       |
| September    | 129,000          | 17                    | 314,000        | 12,400   | 3,310     | 66       |
| September    | 119,000          | 18                    | 290,000        | 14,500   | 4,300     | 43       |
| September    | 90,000           | 16                    | 630,000        | 23,700   | 7,300     | 37       |
| September    | 130,000          | 18                    | 310,000        | 11,650   | 3,250     | 65       |
| October      | 160,000          | 17                    | 241,000        | 8,500    | 2,670     | 59       |

Results are in cells per milliliter

Table 5 Bacteriological Data - 1967

Conclusions:

1. The detention time exerts a bactericidal influence on the coliforms and other bacteria in the wastewater.
2. The rate of destruction of coliform bacteria is greater than the rate of die-away of the total bacteria population.
3. A linear relationship exists between the mean values of total plate count and the number of coliform bacteria.
4. Chlorination of the effluent appears to be necessary.

## Chapter X

THE ROLE OF THE OLIGOCHAETE WORMS IN THE OXIDATION  
DITCH METHOD OF SEWAGE TREATMENT

Chemical, bacteriological, biological data have been collected from the oxidation ditch sewage treatment plant and the stream at Cameron, West Virginia over a period of more than two years. During the period of the investigation an increasing number of oligochaete worms were discovered in the aeration ditch portion of the plant. The purpose of this investigation was to determine the function of the oligochaetes and the conditions which created and favored large populations.

Collection of the worms, separation from the sludge and debris, and laboratory culturing and acclimation presented the first problems. After solving these problems laboratory testing was approached from three aspects. Warburg respirometers, static and continual flow devices, and a gas chromatograph were used to determine respiration rates of the oligochaetes. Effects of thermal, tactile, and chemical stimuli were evaluated through the use of the Warburg respirometers and visual observation. Substrate acceptance and utilization were evaluated with the Warburg respirometers, radioactive tracer techniques, and standard chemical tests.

Temperature, pH, and chemical properties of the water were found to have an effect on the activity of the worms. Results of the respiration studies also indicated that oligochaetes are capable of removing organic chemicals from solution. The worms were found to have an endogenous oxygen demand of approximately 1 mg  $O_2$ /g/hr.

Contrary to published information the worms were found to increase the biochemical oxygen demand, however, the chemical oxygen demand of the substrate was decreased after digestion by the worms. This observation suggested the worms are capable of converting complex organics to a form which is more readily utilized by bacteria.

The sanitary engineer can utilize the activity of the oligochaete worms to achieve better treatment efficiencies in the oxidation ditch method. The increased biochemical oxygen demand created by the worms would readily be removed in an oxidation ditch as the process uses bacteria in the endogenous phase and they would accept additional substrate. The final result would be an effluent with a lower chemical oxygen demand than could be obtained without worms. Although chemical oxygen demand is not a common criteria for treatment plant efficiencies at the present time, the engineer must have at his disposal information that can be applied when conditions demand higher degrees of treatment.

#### Conclusions:

1. The separation techniques and the culturing methods developed were necessary before laboratory testing could be conducted. The methods developed insured a plentiful supply of worms in good conditions.
2. Temperature, pH, and chemical stimuli were all discovered to influence the activity of the worms. A temperature of 20°C was found to be optimum. The respiration rate approximately doubles from 10° to 20°C. The optimum pH was discovered to be between 7.1 and 7.3 which is the range found in the oxidation ditch at Cameron, West Virginia. The use of different waters

resulted in different respiration rates for the worms. BOD dilution water was found to have an effect on the respiration rate similar to the oxidation ditch water.

3. Respiration rate investigations proved that oxygen can be transferred from the atmosphere to the moisture of the skin of a worm and into the body. This discovery led to the development of feeding techniques. As a result of feeding the respiration rate of the worms increased. This increase indicated utilization of food, but these increases were not quantitatively related to decomposition. The continual flow device and the gas chromatograph were not as precise as the Warburg apparatus for respiration studies. The results from the Warburg apparatus feeding method indicated the utilization of dissolved organic chemicals.
4. The evaporation dish feeding method that was developed resulted in a quantitative means for determining the effect of the worm on the environment. The BOD increases and the COD reductions had not been reported prior to this investigation. The results imply worms are capable of reducing complex organics to a form which can be utilized by bacteria. This makes the worm-bacteria combination an effective means for producing better treatment plant effluents. Any substrate produced that increases the BOD would be accepted by the bacteria which exist in the endogenous phase.
5. The worms were found to utilize bacteria as food. The radioactive isotope method proved incorporation of bacteria into the protoplasm of the worm.
6. Several conditions at Cameron contributed to the large population. Equipment failures, overdesigning, high infiltration rates, and other factors helped to create optimum conditions. The pH, oxygen content, and sludge condition are all considered important properties for maintaining large populations.

7. The engineer can utilize worms to provide an effluent of better quality than is achieved by conventional treatment methods. Existing oxidation ditches having an optimum pH and dissolved oxygen content could possibly be altered with a minimum of expense to provide better bottom conditions for the worms. Placing slag or gravel on the ditch bottom would provide voids for sludge accumulations and a niche for the worms. The amount of oxygen needed to support large populations is negligible compared to the oxygen supplied to the bacteria.

## Chapter XI

## SUMMARY AND GENERAL CONCLUSIONS

It would appear from the preceeding chapters that the following general conclusions can be drawn as to the acceptability of an oxidation ditch as a method of waste treatment.

1. BOD efficiencencies are very good, seldom dropping below 90 per cent.
2. Nutrients are added to the receiving stream.
3. Capital and operating costs are low, especially when compared to secondary treatment plants since the per cent removal for the oxidation ditch is in the range of secondary rather than primary treatment.
4. The caged rotor is an efficient method for introducing oxygen into the sewage.
5. A full time operator is not required and operation of the plant is not extremely difficult.
6. Some modifications should be made in the driving mechanism of the rotor.  
(It is believed that this has been done since the installation at Cameron, West Virginia).
7. As in any other plant, the sewer system itself can affect the operation through excessive infiltration or poor design.
8. Some method of grit removal should probably be provided.
9. Detention time in the ditch and possible short circuiting of the flow does not insure complete destruction of coliform organisms without chlorination.
10. The ditch, in most cases, will probably need some type of lining which will not float, in order to make it impervious.

Summing up, the writer feels that the oxidation ditch method of waste treatment is an efficient, economical method for treating wastes from small communities possibly to 10,000 population. Land requirements are not excessive and operation

and maintenance are not difficult. The plant does not produce offensive odors and is pleasing in appearance.

For more detailed information on the studies at Cameron, West Virginia, see the first eight references in the General Bibliography.

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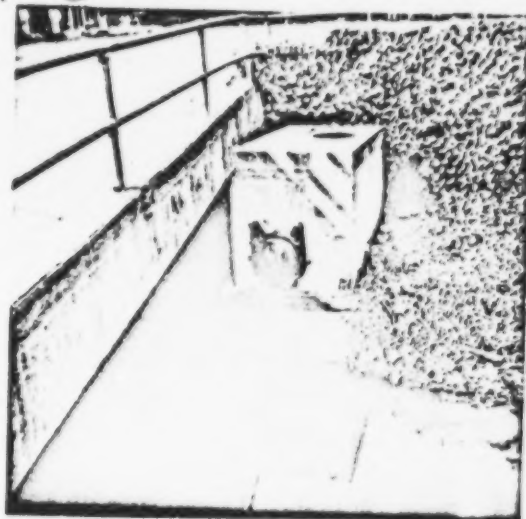
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Photograph 21



Photograph 22